Silicon PIN Diode CMOS Arrays

12 June 2003 – Tony Tyson

Silicon PIN Diodes: A Promising Technology for UV-Optical Space Astronomy

11 April 2003 Presentation at NHST Workshop

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Updated 10 June 2003 – Tony Tyson

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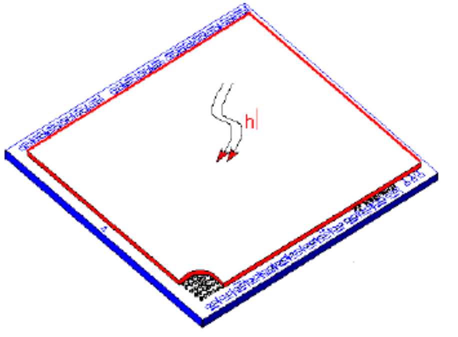
Introduction

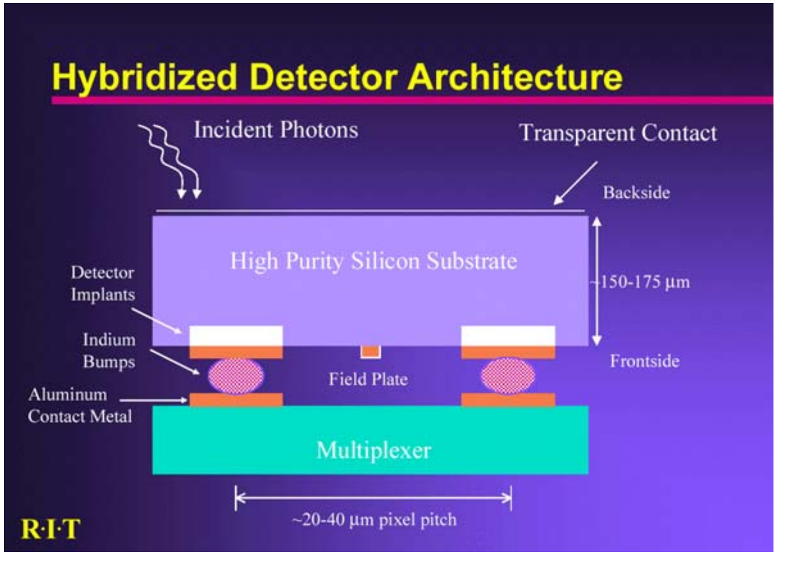
- What is a Si-PIN detector?
- Raytheon Status
- Rockwell Status
- Plans for Testing at STScI/JHU
- Long term Potential

There may be other vendors…

What is a Si PIN Array?

- A hybrid UV-optical sensor, analogous to near-infrared (NIR) array detectors.
- Separation of photon collection from readout facilitates separate optimization of
  - CMOS readout multiplexer (MUX)
  - Si PIN detector array
- Nearly the full bulk of the detector is in depletion. Hence, Si PIN detectors have good QE in both red and blue wavelengths.
- Si PIN detectors are operated at very high bias compared to near-IR detectors. High E field strength means one can expect good MTF and low pixel-to-pixel crosstalk.
- Differs from a monolithic CMOS imager. In a monolithic CMOS imager, both readout and photon detection take place in the same piece of silicon. Si PIN detectors have fill factor ~100%.



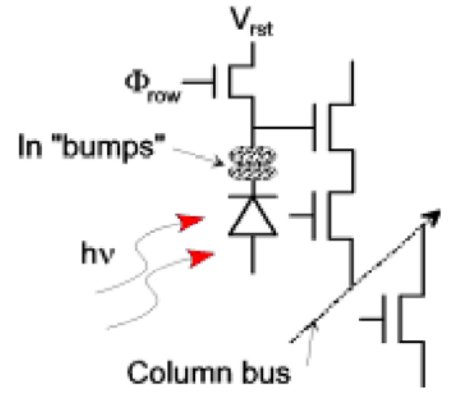


Detectors

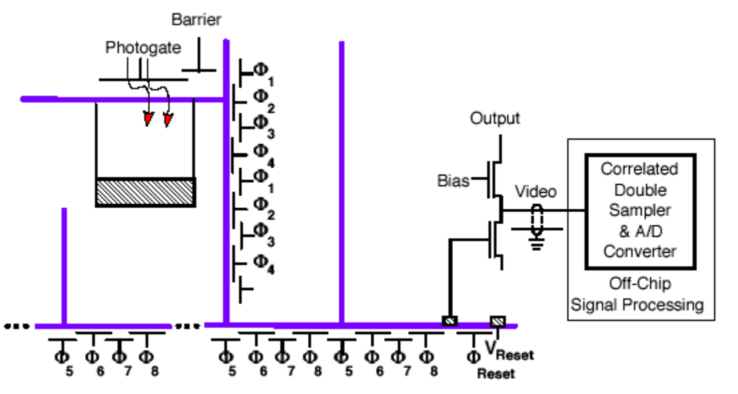
- Example of one detector delivered by Raytheon
  - Detectors were 185 μm thick wafers of high purity silicon.
  - N dopant on illuminated side
  - P dopant on bond side
  - N dopant "one big thin implant, conductive but transparent"
  - Biased to high positive voltage
  - Each pixel is separate P implant
  - 27 μm pitch detectors bonded to 1024×1024 pixels SB226 readout
- Other pixel pitches are available. E.g. Rockwell has bonded Si PIN diodes to HAWAII-class MUXes having 18 μm pitch.

Multiplexers

- A CMOS Multiplexer is used to sense charge in pixels
- Can use astronomy source-follower-per-detector (SFD) multiplexers such as Rockwell HAWAII class and Raytheon SB226
- Low detector capacitance -> lower noise expected compared to near-IR



SFD: Charge sensed in situ

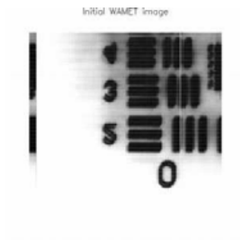


CCD: Charge physically moves during readout

IDTL First Light Images

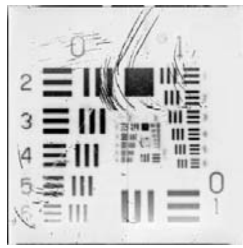
Any of these existing MUXes could be bonded to Si PIN arrays!

Raytheon ALADDIN

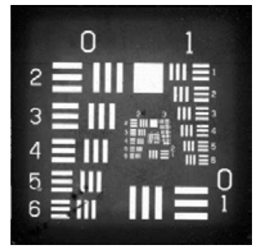


Jan. '01 (MUX)

Rockwell HAWAII-1R

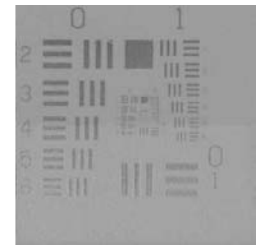


Feb. '02 (MUX)

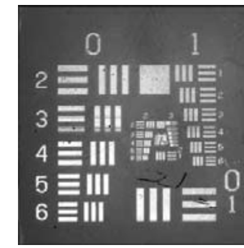


Apr. '02 (SCA)

Rockwell HAWAII-1RG



Jun. '02 (MUX)

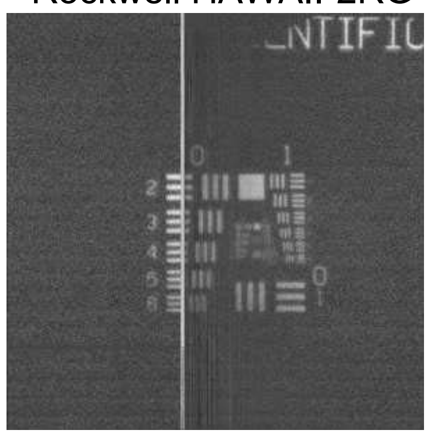


Jul. '02 (SCA)

Raytheon SB-304

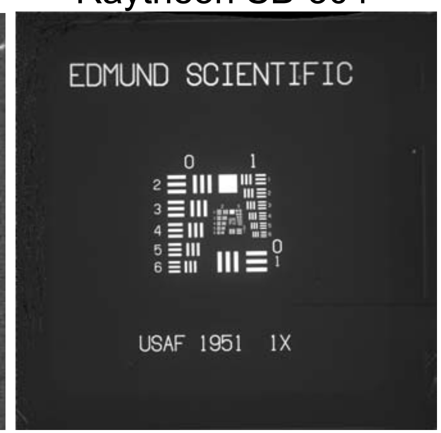
Nov. '02
(MUX)

Rockwell HAWAII-2RG



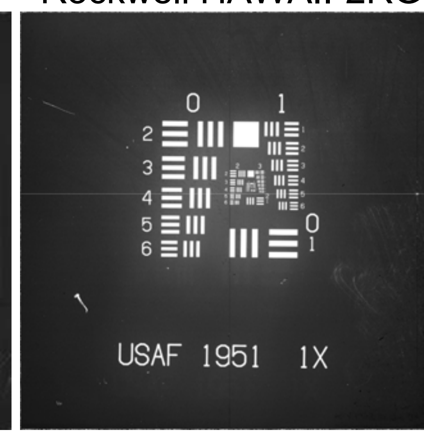
Jan. '03
(MUX)

Raytheon SB-304



Mar. '03
(SCA)

Rockwell HAWAII-2RG



Mar. '03
(SCA)

Advantages for LSST

- No charge transfer -> no CTE degradation
- Requires no mechanical shutter
- SFD architecture does not bloom

• Read noise competitive with CCDs using multiple non-destructive reads
• Excellent QE from UV (with appropriate AR coatings) to ~1 μm
• Multiplexers from two potential vendors have flight heritage.
  - Rockwell -> NICMOS
  - Raytheon -> SIRTF

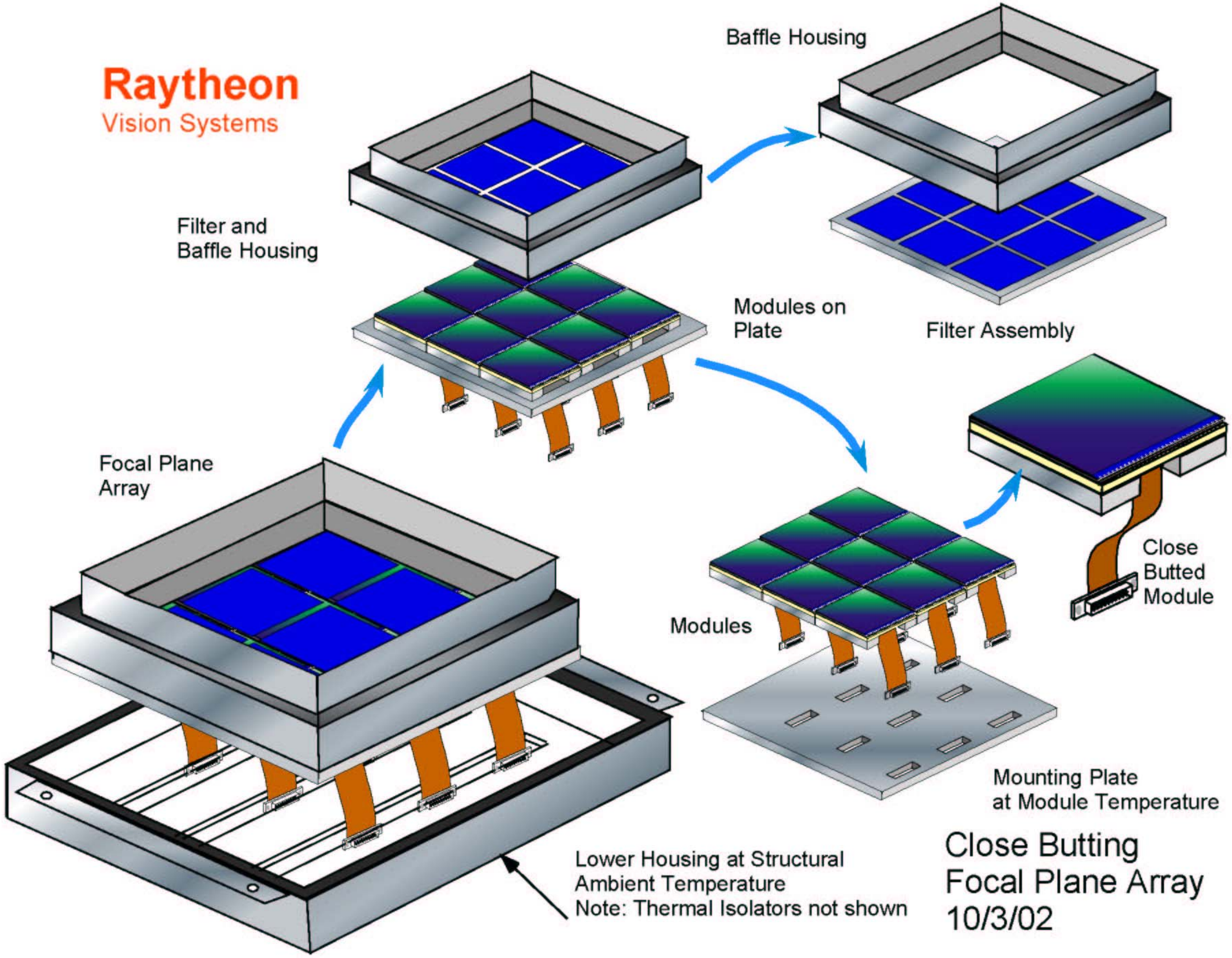
Raytheon Status

- Raytheon has delivered a small number of 1K×1K pixels hybrids to Zorin Ninkov of RIT under a NASA grant
- Ken Ando - “we are building devices in formats much larger than 1K×1K pixels for defense community”
- The RIT devices are demonstrating excellent performance

Raytheon to send parts to STScI to be tested

- Raytheon makes parts that are significantly larger than 2K^2 for a "strategic" customer. That customer has recently indicated a new expanding need for such devices. So, Raytheon is building a new, large facility in Lompoc that will be dedicated to Si PIN arrays.

- This is good news for us.


Raytheon
Vision Systems
Baffle Housing
Filter and
Baffle Housing
Modules on
Plate
Filter Assembly
Focal Plane
Array
Close
Butted
Module
Modules
Mounting Plate
at Module Temperature
Lower Housing at Structural
Ambient Temperature
Note: Thermal Isolators not shown
Close Butting
Focal Plane Array
10/3/02

Current Status: Independent Testing for Astronomy

- RIT testing of a Raytheon Si PIN detector on SB226 MUX
  - Read noise = 7.77 e- per correlated double sample (<4 e- rms expected @ Fowler-16)
  - Dark current = 0.030 e-/s at T=100 K (estimated)
  - “Excellent MTF” Spread due to transverse diffusion ~5.1 μm

Temp K	DC Shift ADU	Noise ADU	Time s	dark current e^-/s
100	–	3.2	1000	0.03
130	–	4.6	1000	0.06
160	–	8.0	1000	0.18
190	–	20.6	1000	1.22
200	–	10.8	300	1.11
210	1900	27	300	7.0
220	10400	114	300	125
240	23000	134	35	1477

RIT measurements. Conversion gain is ~1.8 e-/ADU

- Raytheon went to 4 inch line, and are investing in 6 inch line now (Lompoc).
  Online in 1 year for full production with some parts coming out by the end of this year.

- What is available? They can offer a 1K on a 226 (as they made for Ninkov). Such a device would cost around $300,000 (assuming that they have stock in the 226 ROIC).

- What is capacity? Can they make a billion pixels by 2006? Yes!

- What is cost? Might be able to get to $20K per part at high volume, without lots of QA.

- What will be available? We would need a new MUX design to get to 10 um pixels, but that is not a problem and would represent a tiny fraction of the total cost of the program. They can make any type of design and format to fill up a 6 inch wafer. We would also need 4-side buttable.

- What is delivery schedule? Parts next year, and a billion pixels by 2006.
- Can we piggy-back off of other customers? Not strategic customers, but there is an existing customer who are looking at small unit cell designs.

- What about QE? Probably ok for 60% at 400nm, 80% at 600nm, and 70% at 800nm.

- Negotiations. There is a chance that they cannot even talk about our kinds of requests for a year or so because of security issues.

Rockwell Status-1 (HyViSI detectors)

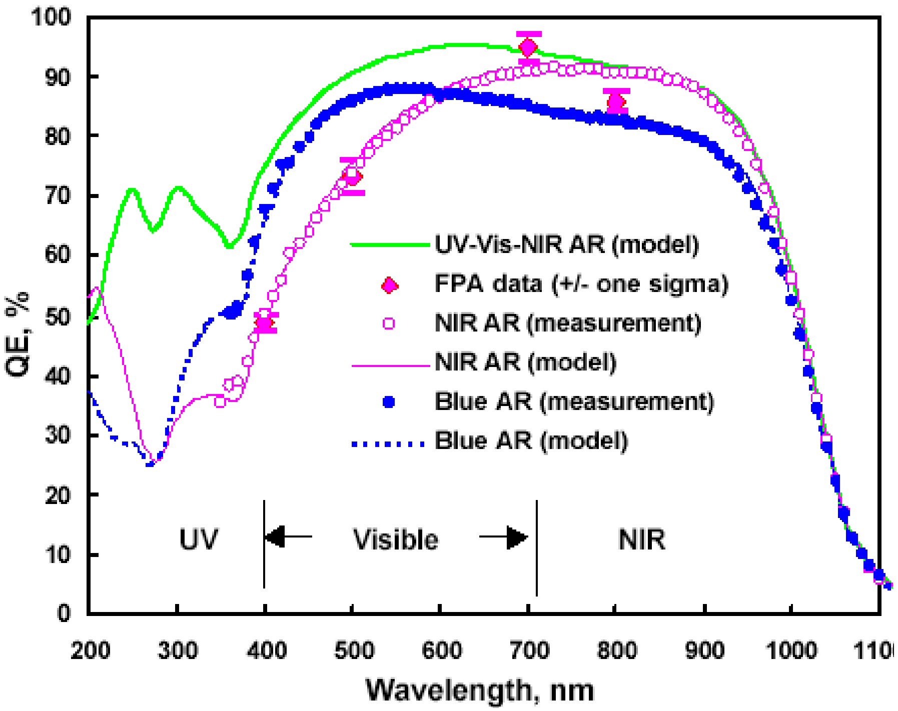
- Gerry Luppino at U. Hawaii has a part for use at telescope
- Rockwell sending a part to STScI for testing, during early summer 2003.
- Rockwell tested a 1K×1K pixel part mated to a HAWAII MUX
  - For this part, they measured read noise =6 e- per correlated double sample (<4 e- rms @ Fowler-16)
  - Full well ~10^5 e-

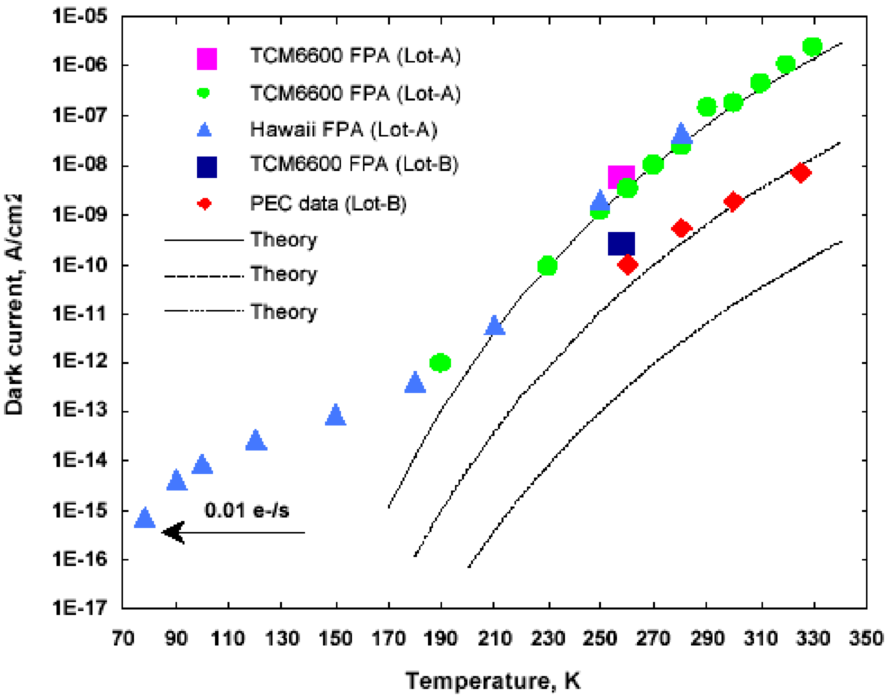
HyViSI Detector Arrays
Now Available in Multiple Formats

Parameter	TCM6600	TCM8000	TCM8050	TCM8600	HAWAII	HAWAII2	Units
Input Circuit	CTIA	CTIA	PCDI	CTIA	SFD	SFD	-
Array Format	640x480	1024x1024	1024x1024	1024x1024	1024x1024	2048x2048	-
Cell Pitch	27	18.5	18	18	18.5	18	µm
Number of Outputs	1	2	4	8	4	4 or 32	
Maximum Frame Rate	22	12	25	50	2	0.5 to 16	Hz
Read Out Modes	Snapshot	Ripple	Snapshot	Ripple	Ripple	Ripple	-
Window Mode	Programmable	na	4 presets	na	na	na	-
Integration Capacity	650,000	580,000	3,000,000	350,000	>100000	>100000	e-
Signal Conversion Gain	4	3.6	1	2-7.4	6.0-10.0	6.0-10.0	µV/e-
Read Noise	50	27	1600	50	3	3	e-
Dark Current @ -15C	9.10E+03	4.30E+03	4.00E+03	4.00E+03	4.30E+03	4.00E+03	e-/sec-pixel
Power Consumption	70	45	150	100	<1	<2	mW

Table from Rockwell's WWW site. See http://www.rsc.rockwell.com/imaging/hyvisi/index.html

Rockwell Status-2 (HyViSI detectors)

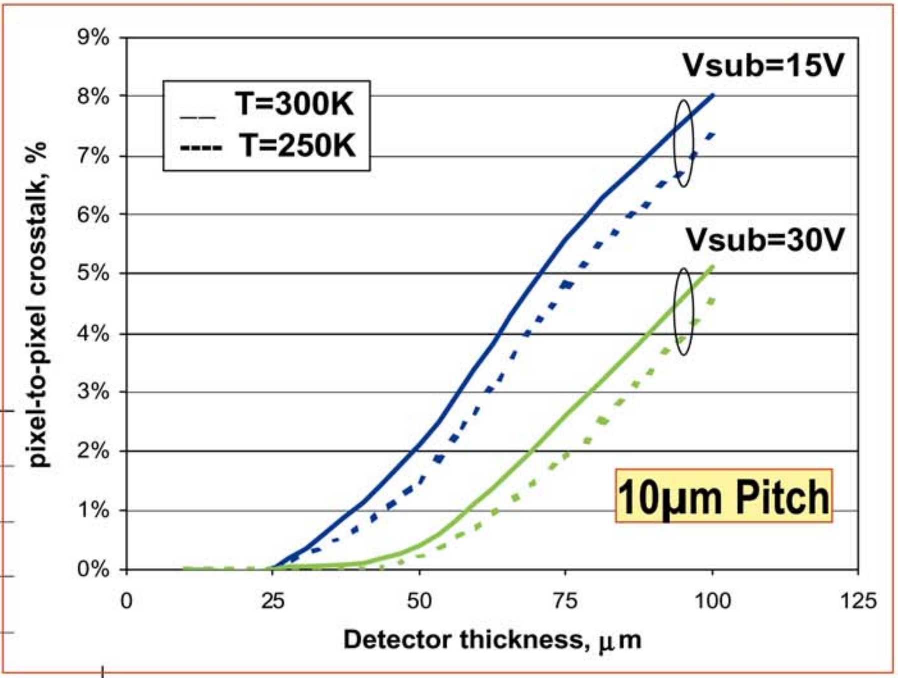


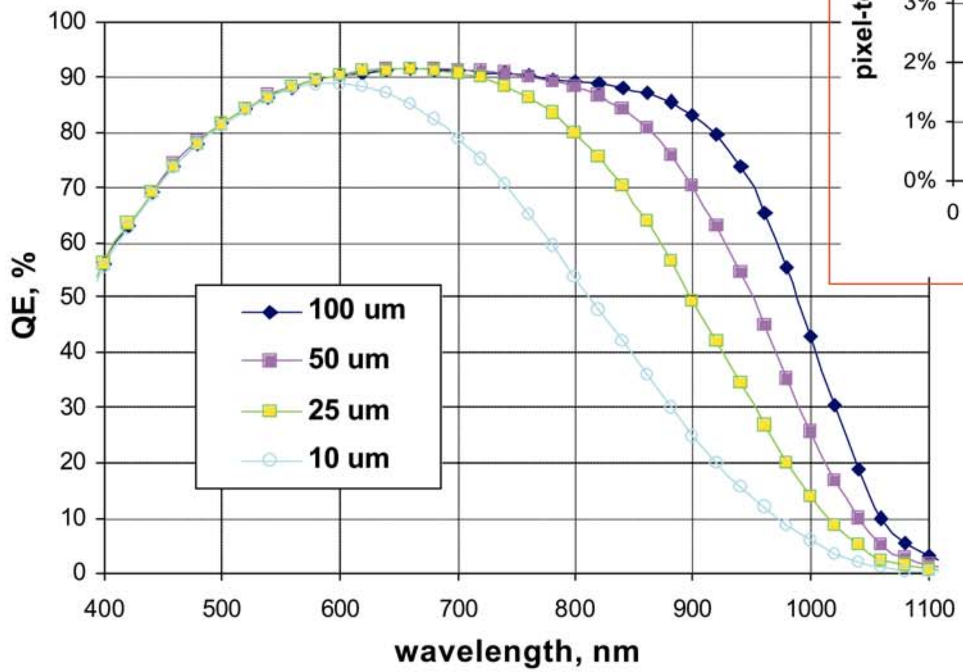


Vendor supplied figures. (left) QE includes both model and measured data. Measured data were obtained using Process Evaluation Chip devices (PECs) and an FPA fabricated on the same wafer. Rockwell says that PEC and FPA QE were in good agreement. (right) Rockwell has measured dark current using a variety of devices.

HyViSI: Trade NIR QE vs. Crosstalk

- e.g., Targeting 70% QE at 900 nm vs. <2% Crosstalk for "~10µm Pitch"





- What is available? 27 um 640X480
  18 um 1K on H1RG (dark current <1e-/s at 150 K)
  18 um 2K on H2RG (demo only, one for Gerry Luppino)
  8 um "very large format" for strategic customers already being made
  They are shipping 10 parts, across all types, this year.

- What is capacity? Hybridization is the bottleneck. Testing could be a bottleneck, unless testing can be done elsewhere. They believe that they can make on order 1000 parts in 2-3 years.

- What is cost? 18 um 1K on H1RG ~$50K for one part.
  1000 parts much cheaper per part (comparable to CCD cost, maybe a bit higher)
  QA can make up as much as 50% of total cost, so this should be relaxed.

- What will be available soon? H2RG.

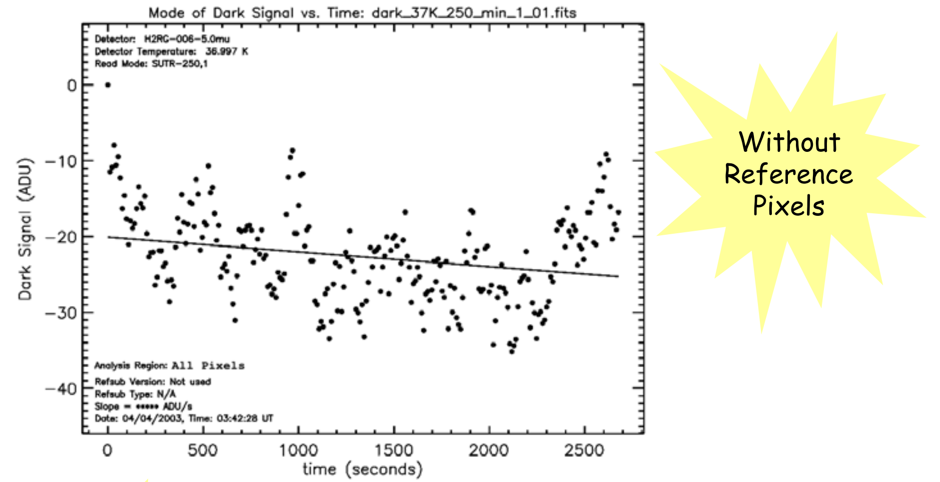
- What is delivery schedule? Start at 0 months, then 6-9 months to ship first part.

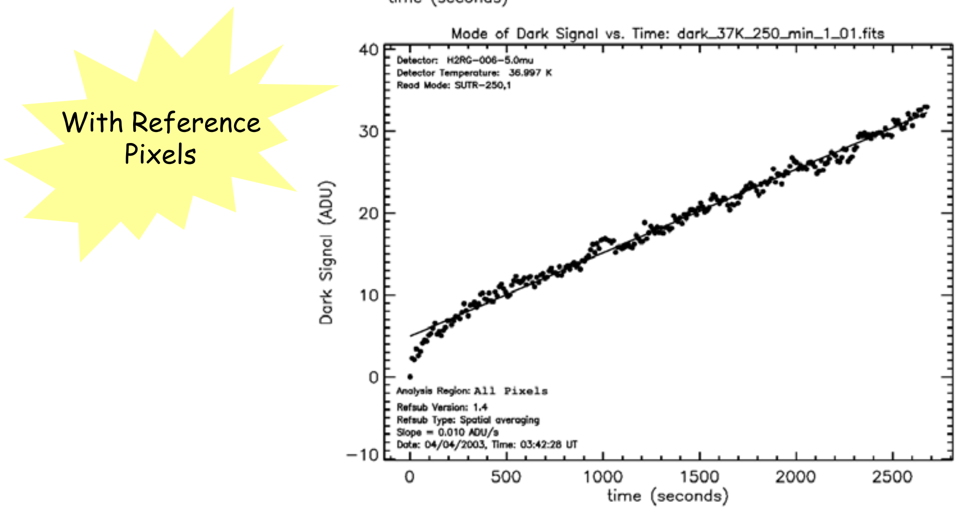
- What quantities? 1000 H1RG parts is possible. 250 H2RG parts is possible.

- They need to do more formal costing to respond properly.

IDTL Experience with JWST MUXes

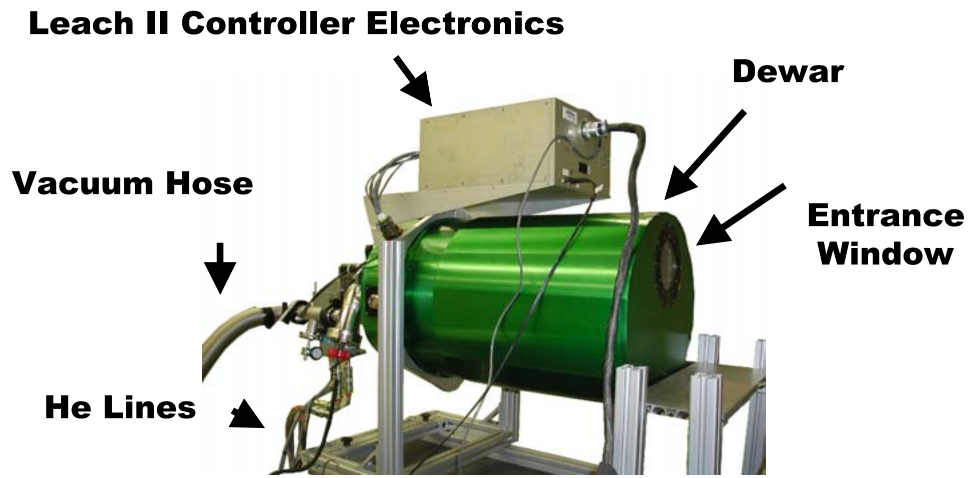
- Systematics will probably determine noise floor, not detectors
- Multiple non-destructive reads reduce noise as expected
- JWST testing demonstrates that reference pixels work!
- Should be possible to achieve total noise with Si PIN arrays substantially below CDS figures given in this talk

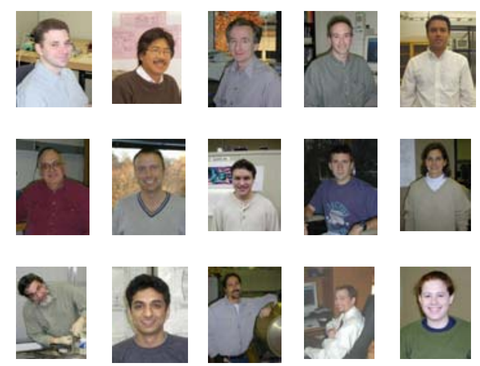




Planned Testing in IDTL

- Dark current
- Read noise
- Linearity
- Latent charge (persistence)
- Relative and Absolute Quantum efficiency (QE)
- Intra-pixel sensitivity
- Thermal stability
- Radiation immunity



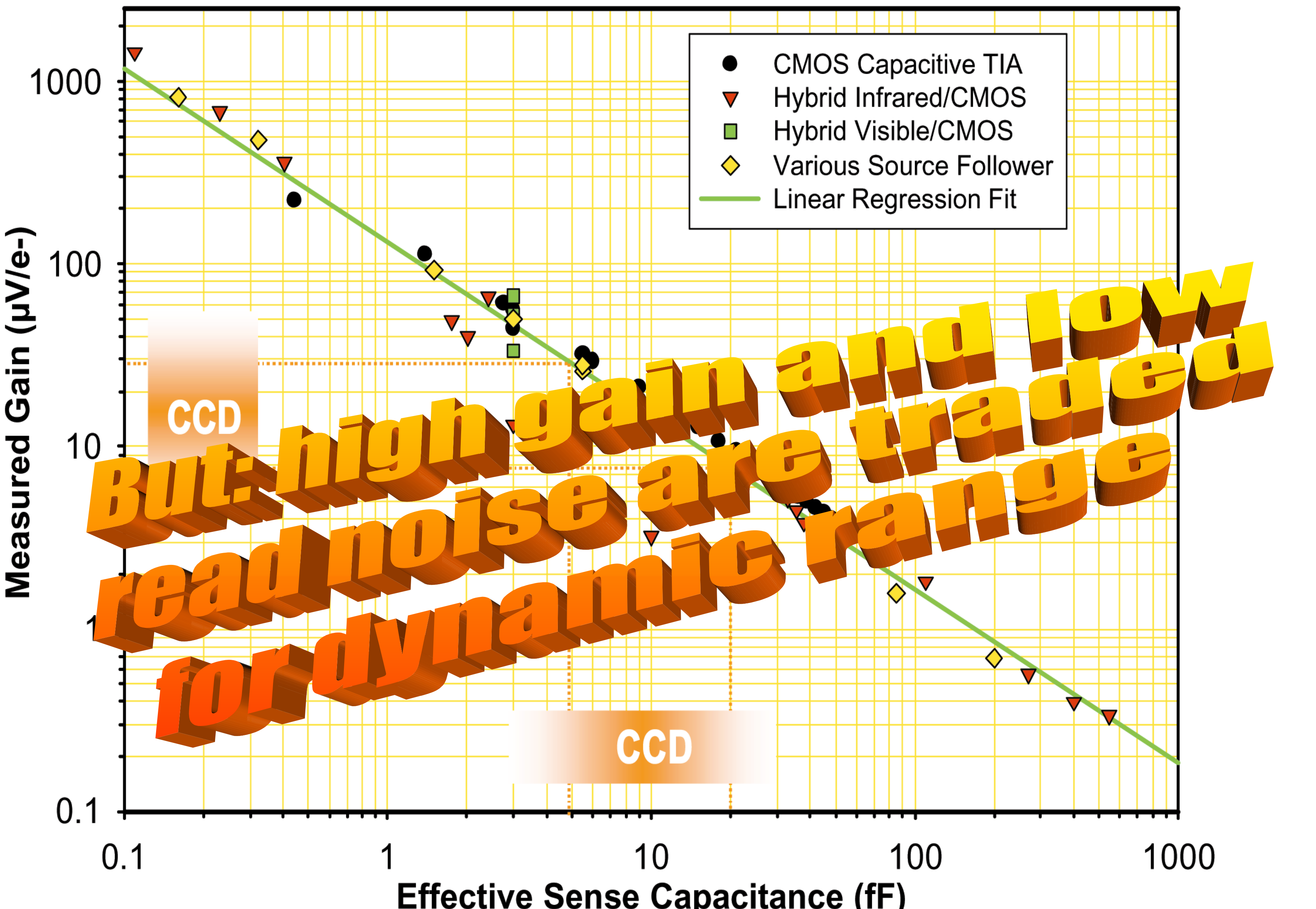


Past and present personnel (incomplete)

Long Term Potential

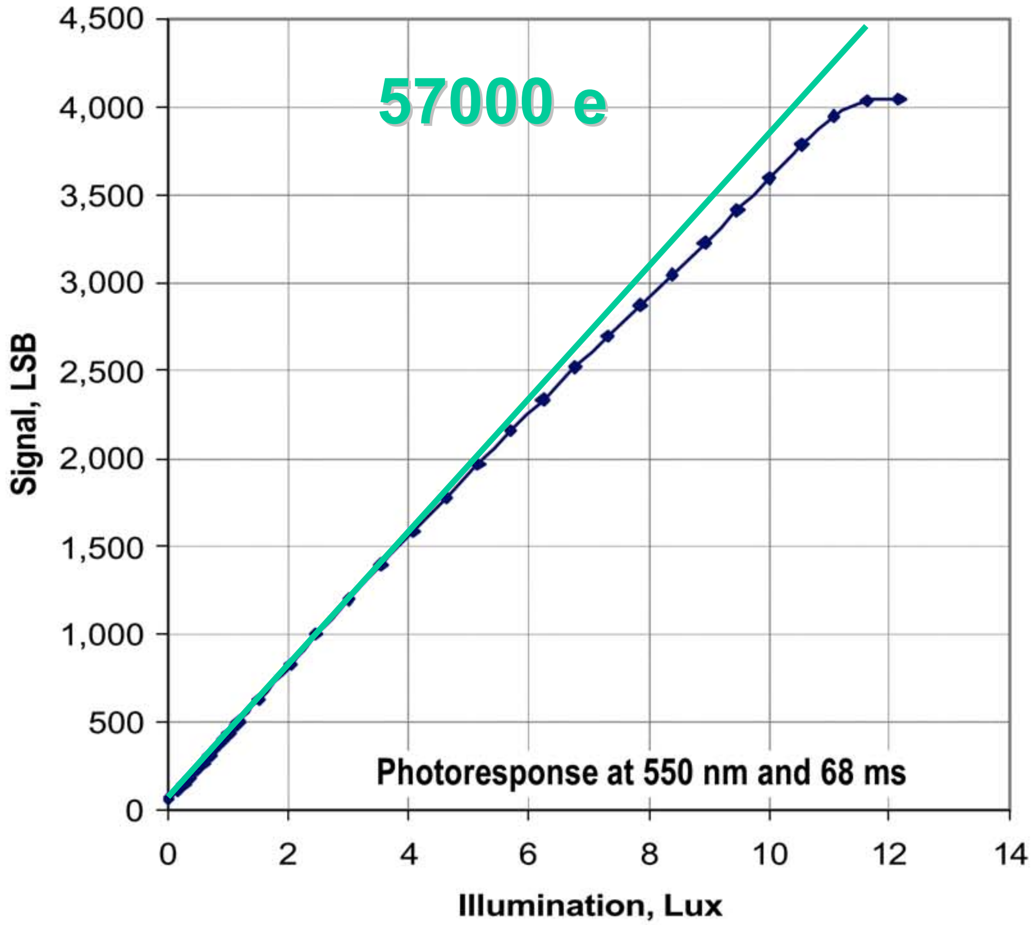
- Technology has the potential to exceed CCD performance
- Key components (MUXes) of the technology are mature and have flight heritage
- There are at least two potential vendors
- Vendors have other customers for this technology.
  - Astronomy benefits from synergy with industry and defense communities

On-Chip Gain can produce large signal for each electron



CMOS: Measured Photoresponse

- Sensitivity
  - 5500 LSB / lx * s
  - 2.2 V / lx * s
- Conversion Gain
  - 0.07 LSB / e-
  - 31 uV / e-
- Nonlinearity < 0.1 %



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IDT Laboratory – LSST Corp Proprietary

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